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B.C. COPPER SMELTER & REFINERY COMPLEX CONCEPTUAL STUDY COMMENTS ON WRIGHT ENGINEER'S DRAFT REPORT

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MICROMEDIA

Executive Summary

1. Capital Costs

The capital costs shown are probably somewhat conservative, particularly for the 150,000 tpy case, but are well within the ± 30% accuracy of the study. The Noranda and Inco processes are likely to have somewhat lower capital requirements, but the reduction in costs is unlikely to exceed about 3% and 9% respectively.

2. Operating Costs

The smelter operating costs documented are too high to ensure competitiveness. Since labour accounts for 50 to 60% of smelter costs, it is apparent that reducing labour requirements will have the greatest effect on total operating costs. However energy requirements for the Outokumpu process also appear to be high. Both Noranda and Inco processes have significantly lower energy requirements and offer the potential for savings of up to about 1¢/lb Cu.

The refinery operating costs documented appear very optimistic. With the flowsheet shown, costs of at least 5¢/lb Cu would normally be expected. To ensure the competitiveness of the smelter/refinery complex, target objectives for total operating costs should be in the 15 to 16¢/lb Cu range. With at least 5¢/lb for refining, smelter costs should preferably be in the range 10 to 11¢/lb Cu.

3. Technical Considerations

All of the four competing pyrometallurgical copper processes (Inco, Noranda, Outokumpu and Mitsubishi) are technically sound, well proven and accepted by the industry. The Kennecott/Outokumpu flash converter, to replace the conventional Pierce Smith, has not yet been proven on a large commercial scale. However major operating problems would not be expected and from an SO_2 capture and fugitive emission

point of view continuous flash converting is preferable to conventional batch converting. The flash converting technology could be used with the Noranda reactor and probably the Inco flash smelter, if economic and/or environmental considerations so warranted.

A tentative ranking of the four competing processes, based on costs, energy and environmental considerations, is shown below.

	Outokumpu (with flash converting)	Inco (with P.S. converting)	Noranda	Mitsubishi
Capital Cost	3	1	2	4
Operating Cost*	3	1	2	4
Energy Consumption	3	1	2	4
SO_2 Control	2	4	3	1

* Assumes labour requirements are similar for all four processes.

4. Environmental Considerations

All of the pyro processes can probably meet the required environmental regulations pertaining to a new B.C. copper smelter. The Inco process with conventional batch converting would have the most difficulty, as the ranking shown above implies. All other environmental aspects are about equal for the four processes and will depend more on impurities in the concentrates and efficiency of gas cleaning than on the process itself.

5. Hydrometallurgical Alternatives

At the present time a hydrometallurgical alternative for copper cannot be recommended because a commercially proven technology is not available. However with the present level of interest and activity and the environmental and economic incentives attributable to the hydro technology (lower capital

costs, better economics at low throughputs (50,000 tpy Cu), no SO_2 emissions and a potentially saleable sulphur by-product), it is quite probable that a hydrocopper process will be commercialized within the next five years. Under these circumstances, as the economic comparison in Table 2 indicates, it is difficult to ignore the hydrometallurgical option and the effect it may have on the future competitiveness of conventional copper smelters. In Canmet's view a chloride based process, incorporating the best features of the GCM and Cuprex processes, is likely to be the most attractive hydrometallurgical alternative for copper.

6. Alternatives to Sulphuric Acid

In Canmet's opinion elemental sulphur is the only alternative which could prove to be more attractive than acid for SO_2 capture. The most promising technology at present appears to be the ESI process, which utilizes low cost coal or coke to provide the energy requirements. Capital and operating costs of the process will have to be compared to acid plant costs and product values to determine the economic incentives for producing elemental sulphur using the ESI technology. Canmet believes that this information can be obtained with sufficient accuracy to determine if the SO_2 to sulphur approach is likely to be viable.

7. Recommendations

1. The potential capital cost savings for the Inco and Noranda smelting processes (versus Outokumpu) should be confirmed to determine the economic inventives for utilizing the Inco or Noranda technology.

2. Labour requirements should be re-assessed and compared for the Inco, Noranda and Outokumpu processes.

3. Energy requirements for the three processes should also be more thoroughly investigated and compared.

4. A new financial analysis should be carried out based on the smelting process which offers the lowest capital and operating costs.

5. Refining costs should be re-assessed and a comparison of the ISA process with the Kidd Creek Mines Copper refinery should be carried out.

6. The economic viability of producing sulphur from SO_2 (using the ESI technology) rather than sulphuric acid should be investigated.

7. A co-operative industry/government R&D project should be promoted to develop a "made-in-Canada" hydrocopper process employing a combination of the GCM and Cuprex processes. With an adequate effort a commercial process could be proven in less than 5 years time.

1. Introduction:

Pacific Rim Metals (PRM) Resources Ltd. retained Wright Engineers Ltd., Vancouver, B.C. to carry out a conceptual study for a custom copper smelter/refinery complex at Kitimat, B.C. The study was financially supported by Western Economic Diversification (WED) and the B.C. Ministry of Economic & Regional Development (MERD). PRM Resources (R.P. Taylor), MERD (J. Rucki) and WED (F. Eichgruehn) requested comments from Canmet (W.J.S. Craigen) on the "draft" Wright Engineers report, particularly with respect to capital and operating costs. This report summarizes these comments and provides recommendations for improving the scope and reliability of the conceptual study.

2. Process Alternatives:

2.1 Noranda Process

The Noranda Reactor should have been included in the assessment of smelting alternatives. The Noranda process, represented by the Horne Smelter in Canada and the Garfield Smelter in the USA, produces a high grade (70-75% Cu) matte similar to the Outokumpu process. However, a concentrate dryer is not required and reactor slag is cleaned by slow cooling, milling and flotation rather than by reduction in an electric furnace. This results in lower slag losses (0.2% Cu) and a higher overall copper recovery (~ 99%) which averages at least 2% greater than other pyrometallurgical alternatives. Fuel requirements are also lower since no reductant is needed for slag cleaning and concentrate drying is not necessary. Noranda reactor matte is normally processed in conventional Pierce-Smith Converters, but could be granulated and flash converted in the same manner as the Outokumpu smelter matte, if this route is considered more desirable from an SO_2 capture point-of-view. Regardless of the converting method used, in

our opinion the Noranda Process is likely to have slightly lower capital and operating costs than Outokumpu.

2.2 INCO Flash Smelter

Although the INCO flash smelting process is included in the Wright Engineers' report, there seem to be some misconceptions with respect to the process and its viability. Inco's flash smelting process is based on producing a discard slag from the smelter by controlling the matte grade to about 50% Cu. All converter slag is recycled to the smelter, so that no separate slag cleaning (electric furnace and/or milling/flotation) is necessary. This eliminates all capital and operating costs directly related to slag cleaning, while maintaining copper recoveries in the range 95 to 97%. Since the process utilizes 100% oxygen, fuel is not required in the smelter, gas volumes and gas cleaning costs are very low and in most cases a waste heat boiler cannot be justified. However the capital and operating cost savings in the smelter are somewhat off-set by increased costs for converting, which include gas handling and cleaning, fugitive emission control and additional acid plant costs related to the variable gas flows from the Pierce-Smith converters. These additional costs can probably be minimized by utilizing the Outokumpu/Kennecott flash converting technology. However, since this technology has not yet been proven commercially for high grade matte, it will probably require considerable testwork on a pilot scale to determine its applicability to INCO's low grade matte. Inco is presently carrying out testwork in Port Colborne related to flash converting of low grade matte.

Regardless of the converting method used, in our opinion the Inco flash smelting process is likely to have lower capital costs and slightly lower operating costs than Outokumpu. It also has the lowest total energy requirements

of all the pyrometallurgical alternatives, provided electrical energy is assumed to be hydro generated and converted at 3410 Btu/Kwh.

A comparison of the pertinent aspects of the Outokumpu, Inco, Noranda and Mitsubishi processes is shown in Table 1. All four processes are well proven and have a high degree of industrial acceptance. Their flexibility with respect to handling dirty concentrates will be more dependent on the converting process used (batch or continuous) and on the efficiency of gas cleaning equipment, than on the smelting furnace operation and design. The Inco process is somewhat less flexible with respect to throughput (turn down ratio) because there is no separate slag cleaning step and matte grade is more or less fixed by the energy balance.

TABLE 1

Comparison of Pyrometallurgical Processes

ITEM	Outokumpu	Inco	Noranda	Mitsubishi
Conc. dryer	yes	yes	no	yes
% O_2 enrichment	$\gtrsim$ 44	95-100	$\gtrsim$ 35	$\gtrsim$ 43
Matte grade (%)	70-75	45-50	70-75	65
% SO_2 from Smelter	25-30	75-85	15-20	30-40
Waste heat boiler	yes	no	yes	yes
Slag cleaning	electric furnace	none required	milling/ flotation	electric furnace
Converting	Pierce-Smith or continuous Flash converting	Pierce-Smith	Pierce-Smith (Flash converting possible)	continuous converting
% of total S from converters	22-25	40-52	22-25	25-30
SO_2 control	very good	good	very good	excellent
Energy req'd (1) (10^6 Btu/t Cu)	7.5-9.5	6.2-8.0	7.5-8.5	9.3-13.0
Cu recovery (%)	96-98	95-97	99+	96-98
Campaign life (yrs)	3-4	3-4	2+	1+

(1) includes refining

2.3 Hydrometallurgical Alternatives

The Gormely Engineering report on Hydrometallurgical routes for copper is essentially correct. At the present time there is not a commercially proven hydrocopper process which could be recommended over conventional modern pyrometallurgical technology. The major, potential advantages of the hydrometallurgical technology over conventional pyro processes are:

- lower capital costs
- no SO_2 produced
- can be economic at low copper production rates (~ 50,000 tpy)
- can produce elemental sulphur and sponge iron by-products, if economically justified

The major disadvantages are:

- not yet commercially proven
- energy requirements higher than pyro
- gold recovery requires separate processing of the leach residue

In Canmet's view the most promising hydro processes at present are the Cuprex (1) and Great Central Mines (GCM) (2). Both are chloride based and can achieve very high extractions of Cu and Ag regardless of concentrate grade or mineralogy. Each process has advantages and disadvantages. The GCM has much lower power requirements (equivalent to modern pyro processes), while the Cuprex has fewer problems producing cathode quality copper. The Cuprex process is presently being evaluated on a pilot plant scale in Spain by a consortium consisting of Tecnicas Reunidas, ICI and NERCO. The GCM process has been tested on a laboratory scale and evaluated for application at Hudson Bay Mining and Smelting (HBMS), Flin Flon, Manitoba (3). The economic incentives for a greenfields GCM process plant, versus conventional pyrometallurgical processes, are summarized in Table 2.

Based on the potential economic viability and the present level of interest and overseas activities, it would not be too surprising to see a chloride based hydrocopper process in commercial use in about five years time. There is sufficient incentive therefore, from a Canadian competitiveness perspective, to seriously consider the hydrometallurgical option for future copper production in Canada, either as a "greenfields" plant or an add-on to an existing smelter. A concerted R&D effort could result in the development of a superior technology, combining the best features of the Cuprex and GCM processes, which conceivably could be commercially proven in less than five years. Canmet has specific ideas on the process flowsheet and on the R&D requirements and is looking for industry support to develop a superior "made in Canada" technology.

TABLE 2

Capital and Operating Costs of Copper Extraction Refining Processes

		Modern Smelters (1)	GCM Process (2)	(3)
Plant Capacity 10^3 Tonnes/Y		65-180	65-75	65-75
Capital Cost $/A Tonne Cu		3,200-5,000	1,800-2,150	2,450-2,600
Operating Cost C/Lb Cu		16-20	18-20	19.5-21.5
By-Product Credit (4) C/Lb Cu	Sulphur	-	2.5-3.5	2.5-3.5
	Iron			4.0
*Capital Charges C/Lb Cu		10-15	5.5-6.5	7.5-8.0
Total Costs C/Lb Cu		26-35	20-24	19.5-23

* Based on 20 year amortization at 10%

(1) Includes smelting, refining and acid production.

(2) Without iron recovery.

(3) With iron recovery.

(4) Assumes no credit or loss for sulphuric acid from smelters.

3. Capital Costs

3.1 Outokumpu Process

The capital costs documented are probably somewhat conservative, particularly for the 150,000 tpy Cu case, but are well within the ± 30% accuracy of the study. Based on other recent cost estimates, the oxygen plant costs could be low by up to 15%. Similarly acid plant costs could be low by as much as 50%, if compared to the cost of Noranda's new acid plant at the Horne smelter. However, acid plant costs are very dependent on gas cleaning costs, which in turn are dependent on SO_2 concentration and the cleanliness of concentrates. Based on the assumption that only relatively clean concentrates will be processed, the acid plant costs documented are unlikely to be low by more than 15%, and total smelter costs are unlikely to be low by more than 6%.

3.2 Noranda Process

Since the Noranda process does not require a concentrate dryer, capital costs could be lower than Outokumpu by about 3%.

3.3 Inco Process

Capital items not required in Inco's flash smelting process include slag cleaning, matte handling and a waste heat boiler and associated turbine. These cost savings are partially offset by increased converting costs and increased oxygen requirements. The net capital cost saving for the Inco process is estimated to be in the 8 to 10% range, when compared to the Outokumpu costs documented.

4. Operating Costs

4.1 Outokumpu Smelter Costs

The smelter operating costs documented for the Outokumpu process are too high for the process to be competitive as a

custom smelter, even if the 15% contingency is removed. The cost estimates are particularly high for the 100,000 tpy Cu case. This appears to be primarily because the figures indicate a scale-up savings in every component of the operating costs in going from 100,000 to 150,000 tpy copper. In fact the savings should be confined essentially to labour, because the cost of fuel, power, consumables and supplies (in $/tonne Cu) should not change significantly in the 100,000 to 150,000 tpy production range. If this correction is applied the operating costs for case 1 (100,000 tpy Cu) should be about 16¢/lb (before contingency) versus about 13.3¢/lb (before contingency) for case 2 (150,000 tpy Cu). This savings of about 3¢/lb Cu is approximately what could be expected from labour "economies of scale" at the higher throughput.

To ensure competitiveness, smelter operating costs should be in the 10 to 12¢/lb Cu range for the copper production rates shown. Since labour accounts for 50 to 60 % of operating costs for most free world copper smelters (Japan and Chile excluded), it is obvious that labour requirements must be reduced. However the energy requirements and costs documented for the Outokumpu process also appear to be high, equating to about 13 million Btu/tonne Cu. This is considerably higher than Inco or Noranda requirements and is even significantly higher than previously quoted Outokumpu figures (see Table 1), prior to introduction of the Kennecott/Outokumpu flash converter. It would appear therefore, that energy requirements should also be further investigated, to determine to what extent these costs (usually about 15 to 20% of total operating) can be reduced.

4.2 Inco and Noranda Smelter Costs

Because of the lower energy requirements indicated in Table 1, the Inco and Noranda processes could have somewhat

lower operating costs than Outokumpu. However, since labour is by far the highest cost component, differences in operating costs between the four competing pyro processes will be primarily dependent on the efficiency of labour usage. Only if the labour component is equal, is there likely to be an operating cost advantage for Inco and Noranda over Outokumpu or Mitsubishi. This advantage is likely to be minimal (1¢/lb Cu).

4.3 Refining Costs

Refinery operating costs documented in the Wright Engineer's report appear to be very optimistic. Present day refining costs are generally in the range 4 to 8¢ US/lb Cu depending on the complexity of the slimes treatment circuit and whether anode scrap melting and casting is included. The proposed refinery flowsheet uses the ISA process but includes anode casting, slimes treatment and a doré precious metals plant. Although the ISA process reduces labour requirements and improves product quality and throughput compared to conventional refining, it is very unlikely that total refining costs will be less than 5¢ US/lb Cu for the proposed flowsheet.

Falconbridge's Kidd Creek Mines division has recently modernized its copper refinery. The technology used was developed by Falconbridge but is similar in nature to the ISA process (stainless steel cathodes). The Falconbridge technology should be considered as a possible alternative to the ISA process for any future studies designed to obtain more accurate capital and operating costs.

5. Financial Analysis

Although the sensitivity analyses have not been completed, there is little doubt that significant reductions in capital and/or operating costs will have to be achieved to

make the ROI reasonably attractive. It is unlikely that capital costs can be reduced to any great extent. However a substantial reduction in operating costs (up to 25%) appears possible if total smelting/refining costs of 15 to 16¢/lb can be achieved. This would be about the minimum required to ensure international competitiveness. Although treatment charge and exchange rates will have an effect, it would not be wise to depend on favourable projected future values for these items for project viability.

6. Environmental Considerations

Under emission controls (section 5.5) it is noted that acid plant tail gas will be scrubbed to reduce SO_2 concentrations to 30 ppm. This is equivalent to 99.97% SO_2 capture, considerably above the 99.5% capture expected without tail gas scrubbing. Although achieving these very high levels of SO_2 capture is obviously possible, it is not very cost effective when measured against the possible environmental benefits from so doing. It is debatable therefore whether tail gas scrubbing is justifiable.

In the weak acid treatment plant, sulphide precipitation is mentioned as the method of precipitating heavy metals, which are then to be shipped off-site for metals recovery. Although sulphide precipitation can be used as an effective method for heavy metals removal, it is highly unlikely that these metals can be marketed and certainly not without incurring additional costs (drying, shipping etc.). Disposal of these metals with tailings will probably be the most cost effective solution.

7. Alternatives to Sulphuric Acid

Based on an estimated netback to the smelter of $5/tonne of acid, which could easily turn out to be negative, the production of sulphuric acid is obviously not very attractive,

particularly since acid plant operating costs will be about double this figure. A possible alternative which should be considered is SO_2 conversion to elemental sulphur, using relatively new technology developed by Engineered Systems International (ESI), Appleton, Wisconsin. The ESI process is presently being tested at Dofasco on a Stretford process bleed stream. Inco has also expressed interest in the technology for possible application at the Thompson smelter, and is presently pursuing studies related to this. ESI has been actively seeking industry/government support for demonstrating the applicability of the process for SO_2 capture from thermal plants and/or smelters and has submitted a proposal (4) for consideration by potential participants.

The ESI process uses an alkali scrubbing media and coal or coke for reduction of the alkali sulphite/sulphate to H_2S which can then be converted to sulphur using conventional Claus plant technology. Capital and operating costs are still being developed. Capital costs may compare favourably with an acid plant, however operating costs will be higher because of the fuel requirements for reduction and heating. Nevertheless, with a potential smelter netback of about $100/tonne for sulphur, the ESI process is worth investigating as a potentially more attractive alternative to acid for a BC copper smelter.

8. References

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